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Original Research Article

Can integrated watershed management reduce soil erosion and improve livelihoods? A study from northern Ethiopia

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ABSTRACT

The study aimed at evaluating the impact of integrated watershed management on reducing soil erosion and changes in the livelihoods of rural farming households in Ethiopia. The changes in soil erosion for the years between 2002 and 2015 were estimated using the Revised Universal Soil Loss Equation model, while the impacts on livelihoods were assessed by household interviews. During the study period, the overall average annual soil loss was halved. Furthermore, crop productivity, water availability (irrigation and domestic) and fodder availability increased by 22, 33 and 10%, respectively, while an increase in household income (by 56%) was observed. Moreover, 72% of the sampled households were able to cover their 12-month annual expenditure demands in 2015, while only 50% of the households were able to cover these demands in 2002. It can be concluded that the implemented integrated watershed management activities seemingly resulted in reduced soil loss, enhanced vegetation cover, and additional household income. This paper also elaborates on the hurdles for integrated watershed management expansion.

1. Introduction

Land degradation has been widely recognized as a major problem that threatens food production around the world (Lambin et al., 2000; Pimentel & Burgess, 2013). Among the major causes of land degradation are unsustainable land use practices and the removal of natural vegetation (Lambin et al., 2000). These changes have important environmental consequences through their impacts on soil and water quality and biodiversity (Lambin et al., 2000; Pimentel & Burgess, 2013; Smith et al., 2013).

Several experiments have demonstrated a rapid decline in soil chemical and physical properties following deforestation and intensive cultivation leading to accelerated soil erosion, a deteriorating soil nutrient status, and declining soil productivity (Iticha et al., 2016). The loss of agricultural land as a result of erosion often results in the transformation of natural ecosystems into new cultivated land and grassland, and the need for additional fertilizer inputs (Pimentel & Burgess, 2013).

The minimum estimated annual cost of land degradation (excluding downstream effects, such as flooding) in Ethiopia is 3% of the agricultural gross domestic product (World Bank, 2012). Land degradation also leads to increased social problems, such as impoverishment, declining productivity, chronic food insecurity, seasonal malnutrition and famines (Yaro et al., 2015).

In response to the negative impacts of land degradation, the Government of Ethiopia, NGOs and communities have implemented environmental rehabilitation activities, such as soil and water conservation measures, exclosures (no human and livestock interference) and water harvesting structures at the watershed scale, which is called integrated watershed management (IWM) (Gebregziabher et al., 2016; Haregeweyn et al., 2012; Yaebyo et al., 2015). Watershed refers to a sub-drainage area of a major river basin (Gebregziabher et al., 2016), whereas IWM is a continuous adaptive process of managing human activities and ecosystems at the watershed scale (CCME, 2016, p. 27). Hence, until 2014, the total area delineated and treated with integrated watershed management activities in the Tigray region was 12,425,869 ha (BoARD, 2016).

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The integrated watershed management (IWM) approach, in Tigray (northern Ethiopia), was initiated in 1997 in collaboration with the Irish development co-operation programme (Irish Aid) (Chisholm & Tassew, 2012). The programme had six major objectives (GIZ, 2015, p. 236): (i) improve food and cash crop production for food security, (ii) improve soil and water conservation, soil fertility and land management using appropriate biological and physical measures and agricultural inputs, (iii) improve multiple water supplies for domestic, livestock and irrigation purposes, (iv) increase household incomes by diversifying agricultural and non-agricultural activities, (v) empower communities' sustainable development of local resources, and (vi) integrate community priorities by community-based health education, hygiene and sanitation, and savings, as well as to increase the status of women and girls in the target communities.

Researchers (e.g., Descheemaeker et al., 2006; Gebremichael et al., 2005; Herweg & Ludi, 1999) have evaluated the impact of different integrated watershed management practices (e.g. exclosures and stone bunds) on soil erosion and run-off reduction separately. However, any positive or negative impact at the watershed level is the cumulative effect of all the activities in the watershed (Chiang et al., 2012). In the Tigray highlands, the establishment of exclosures has become an important measure to combat land degradation (Descheemaeker et al., 2006) and is estimated to cause mean soil loss reduction rates between 26 and 123 ton $ha^{-1}y^{-1}$ as the result of reduced runoff volume and speed. According to Herweg and Ludi (1999), reductions in runoff varied between 10 and 60% due to soil and water conservation measures. Based on measurements on 202 plots, Gebremichael et al. (2005) found that the introduction of stone bunds in Tigray decreased soil erosion by 68%. However, the impact of the IWM implementations on the livelihood of beneficiary rural households had been less documented. Therefore, our aims are to i) map the changes in soil loss and ii) assess the land-based livelihood of households for the years 2002 (before IWM) and 2015 (after IWM).

2. Materials and methods

2.1. Study area

The study was conducted at Gule Watershed, Tigray regional state (Fig. 1). The total watershed area is 1382 ha, with a landscape consisting of rugged hills, high plateaus and valleys. The altitude ranges from 2001 to 2460 m above sea level (m asl). The agro-ecology of the watershed, based on the traditional classification (Hurni et al., 2016, p. 134), is Woina Dega to 84% (midland, dry-warm, elevation between 1500 and 2300 m asl) and Dega to 16% (highland, dry-cold, elevation between 2301 and 3200 m asl). The climate is semi-arid and characterized by erratic rainfall (a mean annual rainfall of 550 mm) and a mean annual temperature ranging from 17 C^{o} (night) to 23 C^{o} (day) between the years 1992 and 2015 (data obtained from the Ethiopian Meteorological Agency, Mekelle branch). Approximately 86% of the annual precipitation falls in the main rainy season (June to September), while 14% falls in the short rain season (February to May). The mean annual potential and actual evapotranspiration, computed using Thornthwaite soil-water balance model (Dunne & Leopold, 1978, p. 818), were found to be 833 mm and 406 mm, respectively (Negusse et al., 2013).

The watershed consists of Gule Village, which has a human population of 4373 individuals (800 households) (Kilte-Awlaelo District OoARD, 2014). The households earn their living from agricultural activities, mainly crop and animal husbandry. Although rainfed practices dominate, the use of small scale irrigation has grown since the last two decades. The average land holding is less than 1 ha per family, 0.6 ha (min 0.2, max 1 ha), and is characterized by traditional technology based entirely on animal traction (Kilte-Awlaelo District OoARD, 2014). The major soils are Leptosols (38%), Regosols (42%), Cambisols (12%) and Fluvisols (8%).

2.2. Implemented IWM activities

IWM activities were implemented by the Ethiopian Catholic Church Diocese of Adigrat Wukro St. Mary's College, with technical collaboration with the local government and beneficiaries who reside in the watershed. The project implementation was also supported by the district's Productive Safety Net Program (PSNP) and the annual soil and water conservation campaign. The key activities include i) physical and biological conservation measures in all land use types (Table 1); ii) water harvesting structures (2 percolation ponds, 3 deep trenches, and 3 cemented gabion (wire basket) check dams) on hill sides; iii) integrated soil fertility management activities (plantation of 20500 trees for agroforestry, and compost production) on farm lands; iv) fuel-saving technologies (672 fuel-saving stoves); v) capacity building of development agents, experts and model farmers (on improved soil and water conservation and management); vi) introduction of livestock (6–12 local sheep breeds per household) and chicken (12 chickens per household) for 672 households.

The tree seedlings and cuttings were planted on hillsides, across gullies and on farmers' fields. Approximately 407 ha of land was rehabilitated and treated by the project, benefitting 615 households (77% of the total). Exclosures, rehabilitating degraded lands through closed areas (Descheemaeker et al., 2006), were introduced. Moreover, community bylaws (i.e., regulations devised by communities) were developed to sustain the exclosures, a common strategy in areas where exclosures are introduced (Yami et al., 2013).

During the project period, soil fertility improvement was the central issue, primarily through agroforestry tree plantation (13325 trees on farmlands and 7175 trees on grazing land), compost preparation, and chemical fertilizer distribution and application. The major agroforestry and multi-purpose trees planted in both farm and grazing lands are *Fehiderbia albida*, *Leucaena leucocephala*, *Sesbania sesban* and *Rhamnus prinoides*. Di-ammonium phosphate (100 kg ha^{-1}) and urea (50 kg ha^{-1}) were the synthetic fertilizer types used in most parts of Tigray (FAO, 2002). In addition to agroforestry and multi-purpose tree planting, grass species such as *elephant grass (Pennisetum purpureum), vetiver grass (Chrysopogon zizanioides), desho grass (Pennisetum pedicellatum) and local bamboo are planted in gullies and grazing lands.* To sustain the agroforestry tree plantation and to further strengthen the adaptation of households to climate anomalies, a zero-grazing approach, in which livestock are tethered at the homestead and fed by a cut-and-carry system (Reda, 2014), was introduced.

2.3. Study method

2.3.1. Soil erosion change assessment

For the assessment of soil erosion rates, the Revised Universal Soil Loss Equation (RUSLE) was used for both years (2002 and 2015). The RUSLE assesses the long-term average soil erosion rate per unit area for inter-rill and rill erosion, expressed in ton $ha^{-1}y^{-1}$ (Wischmeier & Smith, 1978, p. 58). The RUSLE was selected because of its simplicity, but the model has shortcomings since it accounts for rill and inter-rill erosion processes but does not take into account the processes of gully erosion, land sliding and deposition; in fact, no regional scale model considers these processes. Hence, soil erosion by gully, tillage and landslide was not estimated. The RUSLE is a multiplicative model of six factors (eq (1)).

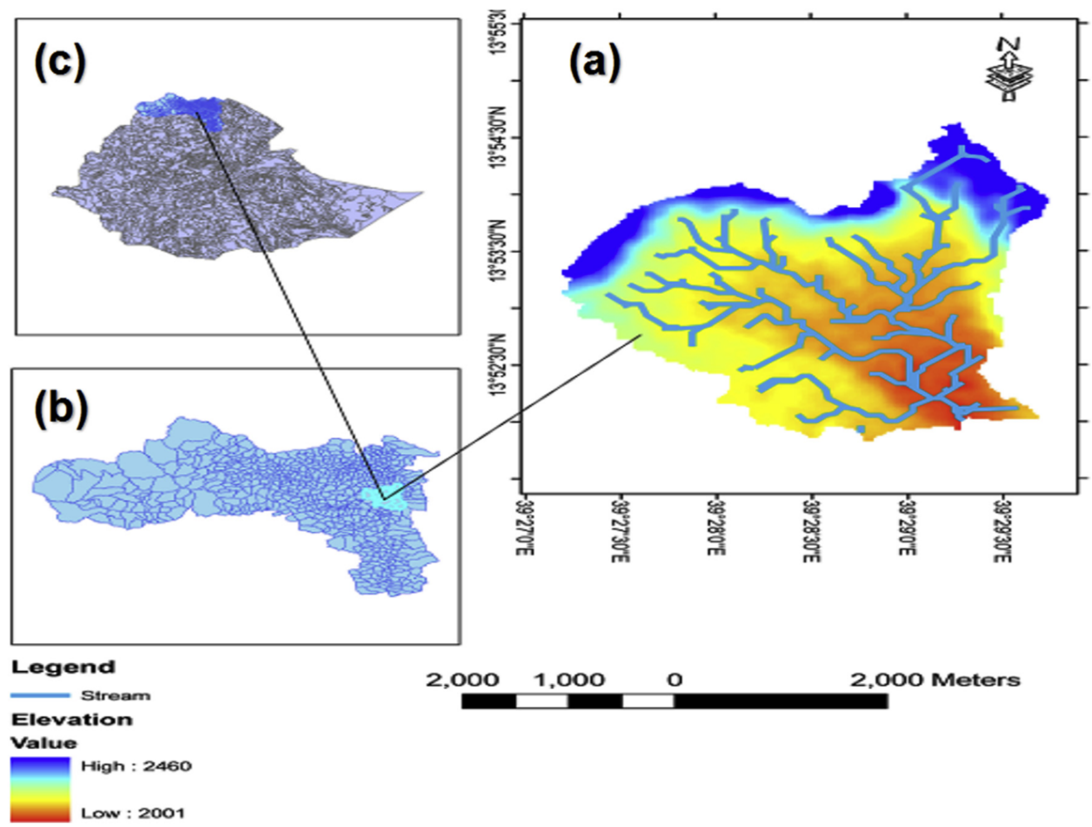

Fig. 1. Location of the Gule Watershed (a) in Tigray (b) and Ethiopia (c) (Source: own map).

Table 1
Implemented soil and water conservation measures.

Physical measures	Unit	Quantity
Gabion check dams	M^3	1564
Loose stone check dams	M^3	11,908
Retention wall	M^3	570
Gully reshaping	M^3	600
Hillside bench terraces	Metre	6394
Bench terraces	Metre	10,931
Tree and cutting seedling plantation	Number	107,270
Percolation pond	M^3	750

Source: own survey (2015)

$$A = R*K*L*S*C*P \quad (1)$$

where A = the average annual soil loss (in ton $ha^{-1}y^{-1}$).

R = the rainfall and runoff erosivity (in mega joule (MJ) mm $^{-1}ha^{-1}hour^{-1}y^{-1}$),
K = the soil erodibility factor (in ton hour $MJ^{-1}mm^{-1}$),
LS = the topographical factor (dimensionless), with L as the slope length factor and S as the slope gradient factor,
C = cover management/land cover factor (dimensionless), and
P = support practices/management factor (dimensionless).

The R factor is assessed if information on the rainfall intensity and its associated kinetic energy is available (Petkovš and Mikoš, 2004). However, due to limited data for the area, the most applicable equation used in northern Ethiopia by Nyssen et al. (2009) (eq (2)) was used.

$$R = 0.562*Pr - 8.12 \quad (2)$$

Where Pr = the annual precipitation (in mm).

Four meteorological stations (Wukro, Hawzen, Senkata and Hagerselam) from around the watershed were used to calculate the rainfall erosivity factor (R value). The monthly precipitation (1992–2015) was collected from the National Meteorology Agency of Ethiopia (Mekelle Branch). The annual precipitation surface was interpolated using hybrid regression Kriging interpolation, which gives cell-based values for the area. This technique is found to be the optimal interpolation method for complex terrains (Yao et al., 2013).

The K factor that describes the soil erodibility for different soil types (Wischmeier & Smith, 1978, p. 58) (Table 2) was adapted from FAO (1989). The soil reference groups of the study watershed were adapted from Rabia et al. (2013) and developed for the district.

The topographic (LS) factor, which is a combined factor of the slope gradient and slope length (Wischmeier & Smith, 1978, p. 58), was calculated using a raster calculator following equation (3). The values for the slope length and the slope gradient were derived

Table 2
Soil erodibility (K) and Crop factor (C) values used in our RUSLE assessment.

Soil type	K-value	Land use type	C-value	Source
Lithic Leptosols	0.1	Bare soil	0.6	BCEOM (1998)
Vertic Cambisols	0.2	Cropland	0.14	Nyssen et al. (2009)
Eutric Fluvisols	0.15	Bare soil	0.6	BCEOM (998)
Eutric Regosols	0.15	Cropland	0.14	Nyssen et al. (2009)

Source: FAO (1989). Reconnaissance physical land evaluation in Ethiopia from Aster DEM (Digital Elevation Model), with a pixel resolution of 30 × 30 m, one of the vital inputs required for soil erosion modelling (Ganasri & Gowda, 2016).

$$LS = \text{Power}(\text{Flow accumulation}*\text{Cell resolution}/22.1,\ 0.4)*\text{Power}\ (\text{Sin}(\text{slope}_{DEM}*0.01745)/0.09,\ 1.4))*1.4 \quad (3)$$

The C-factor value, the ratio of soil loss from an area with a specified cover and management to soil loss from an identical area in a tilled, continuous fallow (Pierce et al., 1984), for each land use type (Table 2) was taken from the works of BCEOM (1998), Eweg et al. (1998) and Nyssen et al. (2009).

The land use types in the years 2002 and 2015 were delineated from TM (Thematic Mapper) and ETM$^+$ (Enhanced Thematic Mapper Plus), respectively (pixel resolution 30 × 30 m). Both images were taken in January after the rainfed crop harvest to avoid confusion between cropland and grassland. The images were enhanced radiometrically and spectrally in ERDAS Imagine 9.3. The different temporal images were cross-referenced with ground truth (102 points) and other ancillary data to make the classification as accurate as possible. An overall land use classification accuracy of 82% was estimated for the year 2015 (Congalton, 1991).

The P factor was assessed on the basis of Table 3 (Nyssen et al., 2008). The activities implemented in the watershed were recorded from a field survey with the help of 102 ground control points and secondary documents.

Finally, by multiplying the different RUSLE-factors described above, the mean annual soil erosion values were determined for each land unit, land use type and slope class for both study years. For a better visual understanding of these quantities, RUSLE values were grouped into five classes of soil erosion risks in accordance with Singh and Phadke (2006) (Table 3).

2.3.2. Livelihood change assessment

The changes in livelihood (water availability, land productivity, and farm and off-farm income) were assessed through semi-structured questionnaires provided to farmers and by the use of secondary sources (reports and CSA, 2008 census documents to cross check the accuracy of the primary data) covering the years 2002 and 2015. As there were no adequate baseline data for the year 2002, an event calendar (a locally known incidences such as the occurrence of extreme drought and the introduction of water harvesting household ponds locally known as 'Horeye' in the area) was developed in consultation with key informants and used in the interviews. This method was found to be an appropriate method in areas where baseline data were absent (e.g., Nyssen et al., 2006; Showers, 1996). The sample size used was 269 households (167 men-headed and 102 women-headed), determined based on the recommendation of Yemane (1967). The interviews were conducted in the months between February and May 2015. Finally, the collected data were analysed using descriptive statistical method.

3. Results

3.1. Erosion assessment results

The present IWM interventions resulted in an overall soil loss reduction for the whole area (1382 ha), with an average loss of 29 ton ha^{-1}y^{-1} in 2002 and an average loss of 14 ton ha^{-1}y^{-1} in 2015 (Fig. 2 and Table 4). The area covered by physical land management interventions (mainly stone and soil bunds) almost doubled, increasing from 15% to 29% during the study period. This could be due to the fact that these structures led to reduced slope length and, therefore, most likely reduced erosion, and they increased soil depth and moisture with time (Wischmeier & Smith, 1978, p. 58).

There is also a change in erosion rate as the result of change in land use. The major land use types and their percent area coverage for the year 2002 were grassland (2%), bush land (13%), bare land (23%) and cultivated land (62%), while the major land use types for the year 2015 were grassland (6%), bush land (23%), bare land (7%) and cultivated land (64%) (Fig. 3 and Table 5).

Even though there is a reduction in soil loss for all land use types, the soil loss rate in the watershed is still high (14 tons ha^{-1}y^{-1}). Moreover, soil loss rates show strong variations in the watershed, which is more associated with the variations in topography and soils types. The overall annual soil loss at the watershed in both years varied between 2 tons ha^{-1}y^{-1} at the foot slope to 57 tons ha^{-1}y^{-1} at the hill slope (Fig. 3 and Table 4). The watershed is dominated by slopes greater than 5% (76% area), followed by 3–5% (20% area), 1–3% (4% area) and 0–1% (0.6% area). Predominant unstable and shallow soil types, such as Leptosols and Regosols, are found on the steep slopes.

3.2. Livelihood changes assessment results

3.2.1. Changes in irrigation and water development

As part of the IWM intervention, new shallow ground waters have emerged, and the water levels of previously existing ground waters have increased by an average of 1 m. At the low part of the watershed, 14 water supply schemes (9 household ponds and 5 shallow wells) were developed for domestic purposes, and 29 hand-dug wells were developed to irrigate 18.6 ha (Fig. 4). In addition to the irrigated area development, a majority (57%) of the sampled households reported that the distance to water points from the homesteads decreased from an average of 1.5 km in 2002

Table 3
Management (P) factor values and soil loss classes.

Quality of stone and soil bunds[a]	P for non-arable land	P for arable land	Soil loss description[b]	Soil loss range (ton/ha/y)[a]
None	1	0.90	Very slight	0–5
Remains	0.8	0.72	Slight	5–10
Poor	0.6	0.54	Moderate	10–25
Moderate	0.4	0.36	Severe	25–45
Good	0.2	0.18	Very severe	≥45

[a] Values & descriptions adapted from Nyssen et al. (2008).
[b] From Singh and Phadke (2006).

Table 4
Soil loss changes in the study watershed.

Class of Soil loss	Soil Loss ton/ha/y	2002		2015		Soil loss change	
		Area (ha)	%	Area (ha)	%	ha	%
Very Slight	0–5	82	5.9	227.1	16.4	+145.1	+10.5%
Slight	5–10	425	30.8	395.8	28.6	−29.2	−2.1
Moderate	10–25	488	35.3	393.4	28.5	−94.6	−6.8
Severe	25–45	285	20.6	293.6	21.3	+8.6	+0.7
Very Severe	45–56.87	102.1	7.4	71.5	5.2	−30.6	−2.2
Total		1381.59		1381.6			

Source: own survey (2015)

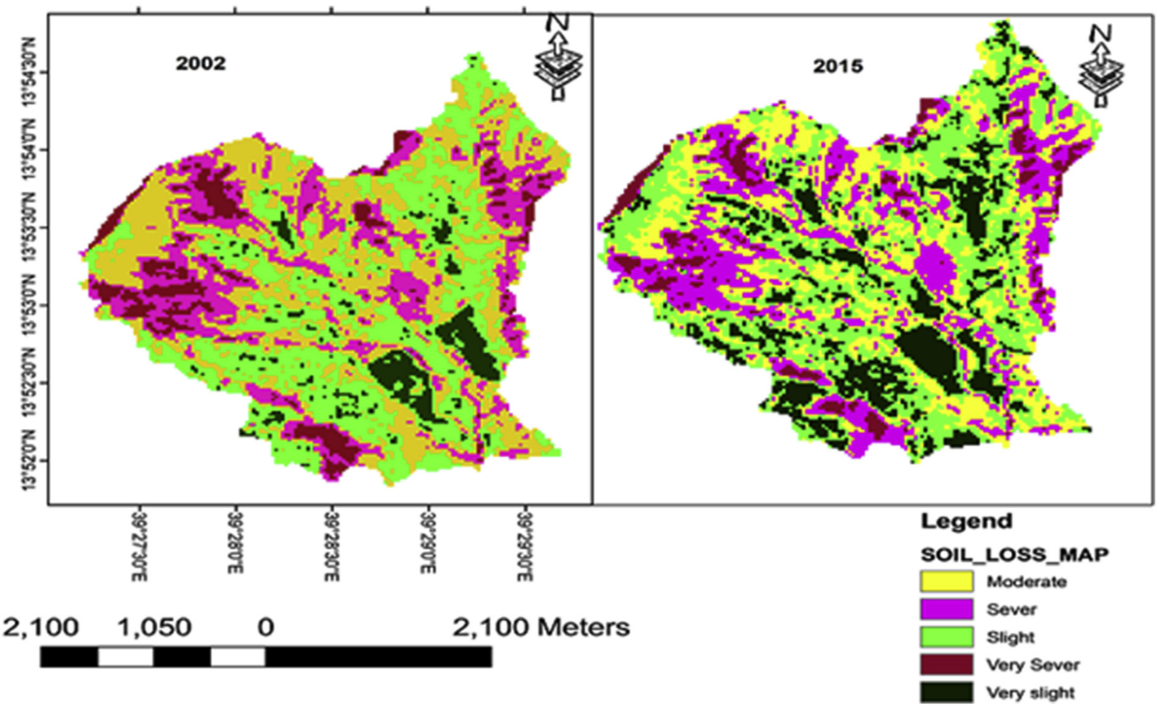

Fig. 2. Soil erosion maps from the RUSLE assessment before and after the IWM introduction (see soil loss rates in Table 4) (Source: own map).

to an average of 1 km in 2015 as new water sources emerged. The domestic water distribution per head also increased from 10 to 25 L per day. Moreover, respondents perceived the water quality and health conditions had improved; the number of households with toilets increased by 188 households, and hand washing facilities were established in 195 households.

3.2.2. Changes in fruit, vegetable and grain crop production

Approximately 47% of the households grew some kind of fruit or vegetable crops in 2015, which did not exist in 2002. Cereal crop productivity also increased in 2015 compared to 2002. The average yield for the dominant crops increased from 1.8 to 2.2 tons ha^{-1} (Table 6). The yield of *Eragrostis tef*, *Sorghum bicolor* and *Zea mays* increased by 62, 61 and 27%, respectively.

3.2.3. Changes in livestock production

From 2002 to 2015, the availability of animal feed increased by 33% compared to the baseline survey in the area. Milk production from local cows increased from 1.5 to 2.5 L per day. While the number of oxen increased by 4% and the number of bee colonies increased by 8%. Only 7% of the produced honey went to the family for direct consumption, while the remaining amount went to the market.

3.2.4. Changes in household income and expenditures

Crops, livestock and their products and off-farm activities are the main sources of household income in the watershed. The responses of the sampled households indicate that the household income improved by 62% since the IWM interventions. Hence, a majority of the respondents (72%) were able to cover their annual expenditure demands in 2015; in contrast, before the IWM activities, only approximately 50% were able to cover these demands. Furthermore, the capacity of the households to cover school expenses and purchase medicine, farm inputs, farm equipment, clothes, livestock, communication facilities such as radios, and additional food items to diversify their food consumption increased (Table 7). Hence, the number of student dropouts was reduced by 34%, and youth migration was reduced by 47%. The Ethiopian Youth Policy defines youth as to include part of the society who are between 15 and 29 years (Broussard & Tekleselassie, 2012).

4. Discussions

4.1. Erosion assessment

As shown in Fig. 3, the mean annual soil loss rate at the watershed for the year 2002 was within the severe soil loss range

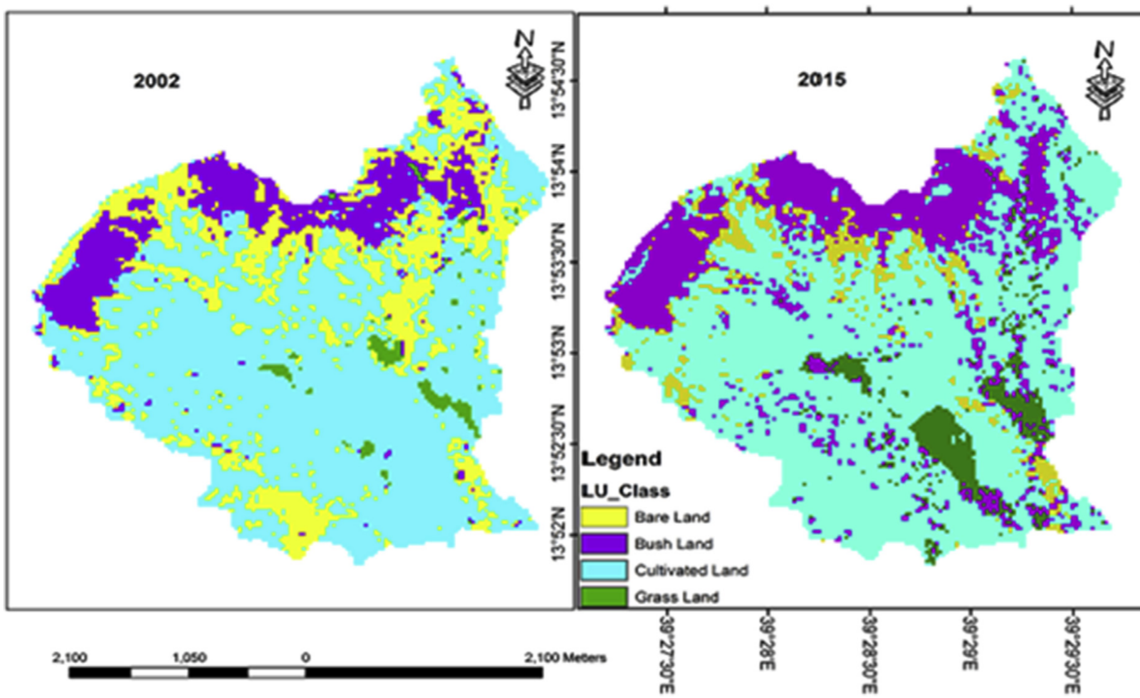

Fig. 3. Land use maps for the years 2002 and 2015 based on Landsat data (see area % in the text) (Source: own map).

Table 5
Soil loss affected by land use.

Land use class	2002		2015	
	Ha	ton/ha/y	ha	ton/ha/y
Grass land	24	4.3	85	3.1
Bush land	182	22.2	312	9.8
Bare land	322	56.8	99	47.4
Cropland	854	20.6	886	12.8
Overall		29		14

Source: own survey (2015)

(25–45 ton ha^{-1}y^{-1}), while it was reduced to the moderate soil loss range (10–25 ton ha^{-1}y^{-1}) in the year 2015. These numbers are still high compared to the maximum tolerable soil loss level (18 ton ha^{-1}y^{-1}) set for Ethiopia (Hurni, 1985) but lower than the findings of Gessesse et al. (2015) for the Modjo watershed and Senti et al. (2014) for the Haramaya Catchment (Ethiopia), where, for both places, a mean annual soil loss rate of 24 ton ha^{-1}y^{-1} was found. Soil formation rate, confined to in situ formation, for the highlands of Ethiopia including the study area was estimated to be from 2 to 22 ton ha^{-1}y^{-1} (FAO, 1986, p. 354). Another study by Bojö and Cassells (1995, p. 56) based on soil formation rates estimated by Hurni and using a rule of thumb on soil depth, reported soil formation rates of 3–7 tons per hectare per year, well below the estimated loss rates. However, these values fall within the extreme range (16–300 tons ha^{-1}y^{-1}) reported by EHRS (1986) in Ethiopia.

The high soil erosion rate in the area is related to the steep slopes and area of bare land on the steep slopes, which contributed to the highest erosion rate, approximately 57 tons ha^{-1}y^{-1}. The dominance of steeper slopes, which represent 76% of the watershed, implies the existence of a large erosion-prone area. Hence, the limited number of physical structures along the contours led to significant losses of soil (Hurni, 1985; Wischmeier & Smith, 1978, p. 58), which cannot be sufficiently stopped by various land covers (e.g., scrubs).

The erosion reduction is most likely highly related to changes in land use due to the IWM interventions. All land use types showed an increase in area, with the exception of bare land (Fig. 2). The increase in vegetation cover might be due to increased onsite soil depth and soil moisture as a result of the interventions and the exclosures (Teka, 2017). The increase in cultivated land might also be due to the implemented bench terraces. A similar study in Eastern Tigray (Teka et al., 2015) indicated that, on some of the rangelands, there are abandoned to exclosures in which shrubs and bushes are allowed to regenerate. Hence, the increase in vegetation cover at the expense of a reduction in the rangeland area implies reduced erosion (Teka, 2017; Wischmeier & Smith, 1978, p. 58).

The assessed physical soil and water conservation structures (e.g., stone terraces and soil bunds) implemented in each land use type revealed that the area of these structures increased with time, implying reduced erosion (Brhane and Mekonen, 2009; Teka, 2017; Wischmeier & Smith, 1978, p. 58). By 2015, the constructed check dams were filled with sediments, and the degraded gullies had become more productive. An experimental study in the watershed (WAHARA, 2015 unpublished report) showed that surface runoff was reduced by 50%. This is very high compared to the findings of Haregeweyn et al. (2012), who estimated a runoff reduction of 27% for southern Tigray. Suspended sediment measurements in streams during the rainy season (WAHARA, 2015) indicated that sediment concentrations were dramatically reduced from 30 g/L (before the intervention) to less than 5 g/L (after the intervention).

4.2. Livelihood changes assessment

4.2.1. Changes in irrigation and water development

In 2015, the inhabitants experienced favourable results, such as improvements in the groundwater levels. Similarly, a groundwater level increase of approximately 5 m was also reported in Abraha–Atsbaha Watershed, northern Ethiopia (Gebregziabher et al., 2016). Negusse et al. (2013) also reported an approximately 10

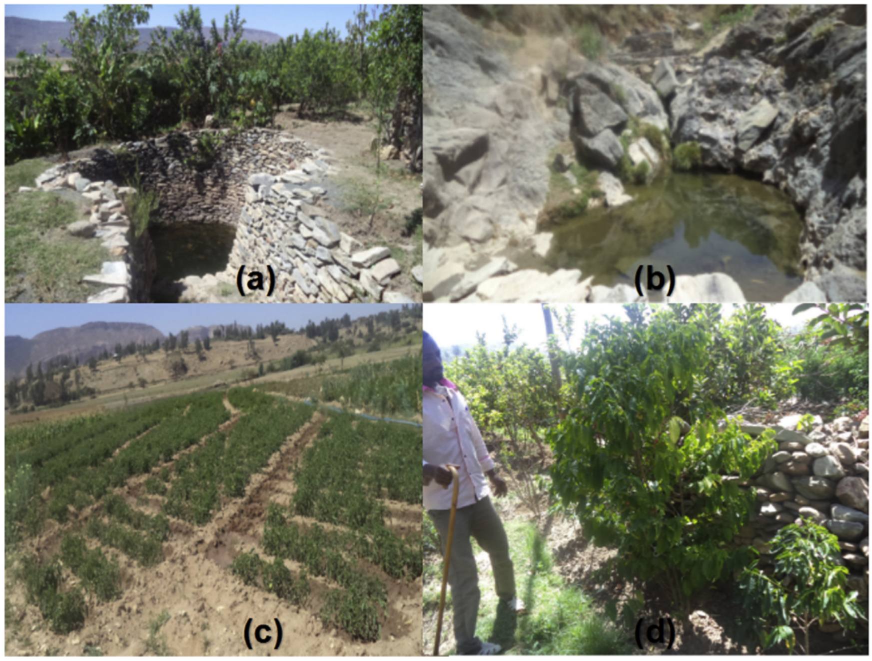

Fig. 4. Shallow irrigation well (a), spring (b), irrigated vegetables (c) and fruits (d) (Source: own map).

Table 6
Change in crop productivity in the study watershed.

Crop type	HH size (n)	Crop productivity (ton ha^{-1})		Change (ton ha^{-1})
		Before	After	
Wheat (*Triticumaestivum*)	240	2.1	2.4	0.3
Teff (*Eragrostistef*)	238	1.4	1.5	0.1
Maize (*Zea mays*)	168	3.1	4.8	1.7
Barley (*Hordeum vulgare*)	157	1.7	2.0	0.3
Sorghum (*Sorghum bicolor*)	168	2.1	2.2	0.1
Beans (*Phaseolus vulgaris*)	160	1.6	1.7	0.1
Peas (*Pisum sativum*)	158	1.3	1.5	0.2
Lentils (*Lens culinaris*)	119	1.2	1.3	0.1
Finger millet (*Eleusine coracana*)	240	1.7	2.2	0.5
Chick pea (*Cicer arietinum*)	178	1.7	1.8	0.1
Average	183	1.8	2.2	0.4

HH = household size, n = number; Source: own survey (2015).

Table 7
Number of HHs and their perception on household expenditures before and after the interventions.

Expenditure Item	HH response to improvement after IWM		
	Yes (n)	No (n)	Change (%)
Purchasing capacity of agricultural inputs and equipment	178	91	66
House improvements	121	148	45
Purchasing capacity of medicine or drugs	179	90	67
Purchasing capacity of household equipment	187	82	70
Purchasing capacity of clothes	178	91	66
Purchasing capacity of animals	164	105	61
Purchasing capacity of radios	164	105	61
Purchasing capacity of crops for consumption	161	108	60
Capacity to pay school fees and expenses	202	67	75
Capacity to rent farm land	144	125	54
Savings in banks	165	104	61

HH = household size, n = number, change (%) = proportion of people responded to change; Source: own survey (2015).

times increase in the groundwater level of Abraha–Atsbaha since 1993. According to these authors, the volume of water that percolated down and joined the groundwater increased from 84,029 m^3 (which is 1.4% of the mean annual rainfall of the catchment before the intervention) to 652,375 m^3 which is 11.1% of the mean annual rainfall of the catchment after the intervention).

The increase in groundwater can be related to the improved soil moisture, run-off and groundwater recharge resulting from IWM interventions (Descheemaeker et al., 2009). Upstream IWM interventions have the potential to alter infiltration into the ground. These interventions can also have an impact on lowering the dry period for wells (Nerkar et al., 2014), leading to an enhanced irrigation capacity of these wells.

The increase in the groundwater level and the emergence of new water sources helped the introduction of irrigation agriculture in the area. The total irrigation area developed during the studied period expanded from zero to 18.6 ha. With irrigation, the farmers were able to produce crops twice a year, which influenced household income. Our findings are in line with earlier reports on the positive impacts of irrigation development in Ethiopia (Gebregziabher et al., 2016; Yaebyo et al., 2015).

The impact of IWM interventions also played a great role in increasing the domestic water supply and water quality, thereby improving health and reducing the distance and time to water points. The distance to water points from homesteads was reduced by approximately 33%, and the per capita water availability increased by 150%. In contrast to the national standard level of service (20 L/head/day) and maximum walking distance of 1 km from the nearest water source (African Development Fund, 2005), the result was found to be higher than the national standard, as the whole population was within a 1 km radius from water and had 25 l/head/day water access. Respondents indicated that this reduced the family workload in general and those of women and children in particular; the saved time is now used for other productive work activities and schooling. Different studies, such as Singh et al. (2010) and Nerkar et al. (2015), have also indicated that women have to walk significantly less to fetch water and the workload of women and children can be reduced by up to 2 h daily in areas where IWM interventions are implemented compared to areas with no intervention.

The increased domestic water availability also influenced hygiene and sanitation practices, which ultimately have an impact on human health. The number of households with toilets increased by 188, and the number of households with hand washing facilities increased by 195, reducing the open-air defecation practice and contamination of water sources. Consequently, respondents perceived the water quality and their health conditions had improved. These results are supported by Nerkar et al. (2014, 2015), that reported a significant decrease in the illness risk of people living near their water source. A study from India confirmed that water sample contamination by *Escherichia coli* was 2.3 times lower in areas with IWM intervention compared to control areas (Nerkar et al., 2014). Other studies, such as Cairncross and Cuff (1987), have linked water access to increased water use for food preparation, thereby influencing the quantity and diversity of diets.

4.2.2. Changes in fruit, vegetable and grain crop production

The implementation of IWM interventions appears to have an influence on the production and choice of food grains, vegetables and fruits. Our results showed that previously degraded areas and gullies have been rehabilitated and reclaimed, allowing farmers to grow fruits, forages, trees and vegetables. Prior to the implementation of IWM activities, cropping systems were purely rainfed, and they were limited to the cultivation of cereal crops and pulses. By 2015, however, crop diversification had occurred on both irrigated and rainfed farms, and farmers had started to produce high-value irrigated crops and fruits for the market.

Studies have indicated that crop diversification not only provides a wider choice in the production of various crops but also minimizes risks and increases profitability, in addition to harnessing the maximum potential of land, water, humans and climate (Gebregziabher et al., 2016). The improvement was not limited to crop diversity; it also applied to crop productivity. The average crop productivity for the dominant crops increased from 1.8 to 2.2 ton ha^{-1}, by 0.4 ton ha^{-1} (approximately 22%). The cereal yield in the 2015 harvest year was equivalent to the national average which is 2.3 ton ha^{-1} (CSA, 2015). This result is also in line with the findings of Yaebyo et al. (2015) that reported a yield increase of 0.7 ton ha^{-1} (44%); however, it is much lower than the findings of Gebrgziabher et al. (2016) that reported yield increase of 1.9 ton ha^{-1} for similar crops. This indicates that an increase in the availability of water, soil fertility and developmental efforts in IWM interventions might influence and increase the variety and productivity of the cultivated crops.

4.2.3. Changes in livestock production

In most parts of the Tigray region, grazing lands are common property resources. Most of the grazing lands are grazed and trampled the entire year, without any resting period, resulting in the depletion of edible species for livestock and the invasion by less edible species (Hags et al., 1999). In our case, due to overgrazing on most of the pasturelands and to watershed degradation, access to water and animal feed was the most important problem for livestock development prior to the watershed intervention. The stall feeding of livestock was not a common practice in rural Tigray in 2002, before the IWM (Gebremedhin & Swinton, 2003). Animals had to travel long distances, particularly in the dry season, for watering and grazing on communal land. This may negatively influence the productivity of small-holder farmers and animal health and productivity. Following the IWM interventions, however, the availability of animal feed (both green and dry) increased significantly, leading to increased stall feeding. According to Gebremedhin and Swinton (2003), stall feeding can increase the availability of manure and reduce the energy loss of livestock due to the reduced walking time during the search for feed. Furthermore, under IWM interventions, yearly milk production from local cows increased by approximately 67% per head. This value is much higher than the findings of Yaebiyo et al. (2015) that reported a 12% increase in the milk yield of local dairy cows after IWM in northern Ethiopia. The change in milk production has a direct impact on greenhouse gas (GHG) emissions. According to Gerber et al. (2011), the emissions of GHGs such as methane and nitrous oxide decrease with increasing productivity. An increase in milk productivity, therefore, offers a pathway to satisfying an increasing demand for milk and is a viable GHG mitigation approach, especially in areas such as the studied watershed, where milk yields are currently below 2000 kg $cow^{-1}y^{-1}$ (Gerber et al., 2011).

An 8% increase in the number of bee colonies was also observed from 2002 to 2015, and it encouraged 72 landless people and youngsters to become involved in honey bee and colony production. This corresponds with the findings of Yaebiyo et al. (2015), who reported a honey bee yield increase of 24%. Moreover, approximately 7% of the produced honey is consumed by the family, which contributes to the family livelihood by providing a highly nutritious food product. This value is, however, smaller than the household consumption (38%) reported for the nation (Ethiopia) (Alemu et al., 2016).

4.2.4. Changes in household income and expenditure

After the IWM intervention in 2015, the household income improved by 62% (cal.13600 birr or 680 USD). These results are twice the findings of Yaebiyo et al. (2015) that reported a 31% household income improvement due to the income generating activities of IWM, such as crops, bee-keeping and dairy. Taking the wealth category scale developed by USAID (5600 Ethiopian birr or 280 USD per capita per year), 79% of the irrigation users were in a higher well-being category, whereas only 34% of non-users were in this category. However, changes in household economy are complex, and it is difficult to ascribe simple causal relationships to a particular intervention.

The increase in income has encouraged households to invest in various activities, which can improve their livelihood. The major investments were in education, health, communication, construction and the purchase of farm tools. This evidence supports the findings of Nerkar et al. (2015) and Gebregziabher et al. (2016), which revealed an improvement in household expenditures on agricultural inputs, house improvements, schooling and medical expenses due to IWM. A study in other parts of Ethiopia (Asayehegn, 2012) also reported that the number of irrigation users who completed nine years of schooling and above was two times higher than that of non-users. This was further supported by the findings of Yeabiyo et al. (2015) in northern Ethiopia, which indicated that the mean education of irrigation users was 3 times higher than that of non-users.

4.3. Hurdles for the scale-up of IWM technologies

The benefits of the IWM approach in addressing the interrelated problems of land degradation, low agricultural productivity and food insecurity are widely recognized by the government and development partners (Tesfaye et al., 2016). Regardless of its benefits, its sustained development and expansion are challenged by various factors. Some of the challenges considered are as follows:

i) The high investment and maintenance costs of IWM technologies: Tesfaye et al. (2016) estimated the cost of some IWM technologies in three watersheds (Ethiopia) and found that the investment costs of soil bund, stone bund and fanyajuu bund construction were USD 29, 33 and 87 per ha, respectively. Moreover, they estimated a maintenance cost of USD 5.2 $ha^{-1}y^{-1}$ for soil bunds, USD 1.7 $ha^{-1}y^{-1}$ for stone bunds and USD 6.1 $ha^{-1}y^{-1}$ for fanyajuu. These investment and maintenance costs are indeed an obstacle for up-scaling the activities.

ii) Inadequate community participation: It is still a challenge in some areas to negotiate and convince farmers to participate in IWM. Inadequate community participation in the planning process of many watersheds, which mainly focuses on technical and physical activities with less attention to the economic viability and social acceptability aspects, has led to the reluctance of some farmers. Moreover, the lack of properly integrating introduced practices with indigenous knowledge limits the willingness of farmers to participate and their responsibility for the assets created (Chimdesa, 2016).

iii) Weak linkages among concerned institutions: In the IWM practice, the level of coordination among researchers, extension centres and educational institutions is relatively poor, which affects the development and transfer of technologies from researchers to local experts and local communities, particularly farmers (Chimdesa, 2016).

iv) Staff mobility: The frequent restructuring of government institutions causes staff turnover, which leads to the discontinuity of activities and initiatives. These all result in limited up-scaling of successful sustainable environmental management practices in the country.

v) Dependency on incentives: The food- and cash-for-work programmes are believed to reduce the confidence of farmers to work independently, as they increase dependency (Little, 2006), which in turn affects the sustainability of the programme negatively. Cash and grain payment incentives to compensate the labour of food-insecure rural households are provided with the support of the World Food Program and PSNP for most months during the year. These are believed to affect the sustainability of IWM interventions, though, because i) when the farmers graduate, their willingness to participate and work in IWM decrease; ii) the food-secured households are less involved and are unwilling to participate in a massive amount of work (Chimdesa, 2016).

vi) Land and tenure security: Even though land certificates are provided to households to create a sense of ownership, this certificate is only awarded to farmlands. Other land uses remain under state ownership, which again creates a limited sense of ownership, and the sustainability issue remains in question (Gorfu, 2016).

vii) Frequent change in IWM technologies: There are changes in technologies from time to time; for example, bench terracing replaced the existing technologies prior to the impact evaluation. Farmers, therefore, lose confidence in the introduced technologies and their sustainability and effectiveness.

vii) Farmers' preference for short-term benefits: IWM, by its very nature, is a long-term investment discouraging small-scale, resource-poor farmers from obtaining short-term benefits (Mekonnen & Fekadu, 2015). Since the main occupation and means of livelihood for rural communities is agriculture, farmers have less interest in long-term conservation investments. Rather, they prefer interventions and watershed technologies with quick returns (Chimdesa, 2016). Farmers living in densely populated areas, with a low per capita land holding, prefer to use communal land to graze and browse their herds. Hence, they are reluctant to apply or implement measures on communal land because they are inclined towards their short-term benefits such as feed for their herds, timber andfuel wood sources (Mekonnen & Fekadu, 2015). These require the provision of farmers with agricultural technologies, such as improved crops, forage, animal breeds and practices, to compensate their short-term interests, which has been the case in many successful watersheds, including the studied watershed. However, this requires additional investments and external support.

5. Conclusions

The results from this study show that integrated watershed management (IWM) offers a promising land resources management and development solutions. It enabled new opportunities linked to crops diversification, land reclamation, fertility improvement, and off-farm activities (e.g. sand mining, cash/food for work).

The IWM activities also increased: 1) knowledge among the population on a variety of topics (natural resources management, agriculture and irrigation techniques & beekeeping); 2) the number of children in school and ability to pay school fees; 3) time-saving for women to collect water and fuel wood; 4) natural resources management interventions in the way of soil and water conservation, resulting in raised water tables and allowed new water sources development. As the result of massive mobilization, groundwater levels have risen, soil erosion has reduced, and people's ability to grow food and gain, and income has improved.

It can be concluded that the model for restoration of degraded land, IWM, sets an achievable example for other African countries. However, the expansion of the technology is challenged by hurdles. To overcome these hurdles, farmer-extension-research-policy integration should be lifted to high level.

Declaration of competing interest

All authors confirmed that there is no conflict of interest and no any ethical issue in relation to this work/paper.

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